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Equatorial Ground Ice on Mars: Steady-State Stability; Michael T. Mellon [1], Bruce M. Jakosky [1], and Susan E. Postawko [2]; [1] Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309, [2] School of Meteorology, University of Oklahoma, Norman, OK 73019.

Introduction: Current Martian equatorial surface temperatures are too warm for water ice to exist at the surface for any appreciable length of time before subliming into the atmosphere. Subsurface temperatures are generally warmer still and, despite the presence of a diffusive barrier of porous regolith material, it has been shown by Smoluchowski, Clifford and Hillel, and Fanale *et al.* that buried ground ice will also sublime and be lost to the atmosphere in a relatively short time. We investigate the behavior of this subliming subsurface ice and show that it is possible for ice to maintain at a steady-state depth, where sublimation and diffusive loss to the atmosphere is balanced by resupply from beneath by diffusion and recondensation of either a deeper buried ice deposits or ground water.

Steady-State Stability: We examine the behavior of equatorial ground ice with a numerical time-marching molecular diffusion model. In our model we allow for diffusion of water vapor through a porous regolith, variations in diffusivity and porosity with ice content, and recondensation of sublimed water vapor. A regolith containing considerable amounts of ice can still be very porous, allowing water vapor to diffuse up from deeper within the ice layer where temperatures are warmer due to the geothermal gradient. This vapor can then recondense nearer to the surface where ice had previously sublimed and been lost to the atmosphere. As a result we find that ice deposits migrate to find a steady-state depth, which represents a balance between diffusive loss to the atmosphere through the overlying porous regolith and diffusive resupply through a porous icy regolith below. This depth depends primarily on the long-term mean surface temperature and the nature of the geothermal gradient, and is independent of the ice-free porosity and the regolith diffusivity. Only the rate of loss of ground ice depends on diffusive properties.

Figure 1 shows the steady-state depths (calculated from an analytic model) as a function of mean surface temperature and geothermal gradient. For reasonable values of the geothermal gradient within an ice-free regolith (around 10^{-3} K/cm) and equatorial surface temperatures for the current epoch (200 to 220 K) depths range from 50 to 100 m. Figure 2 shows an example of a numerical simulation. The regolith is initially full of ice. Water sublimes from the top of the ice deposit and is lost to the atmosphere. Once a steady-state depth is reached the top of the ice is replenished by diffusion through the ice. When pores open up throughout the deposit overall loss occurs from the bottom.

The precise steady-state depth at a particular location will be complicated by deviations from a simple linear geothermal gradient caused by changes in thermal conductivity with depth above the ice layer and by variations in ice content within the ice layer. Long-term changes in climate due to orbital oscillations will also affect the depth by causing changes in the mean surface temperature, producing subsurface oscillations in temperature and in some cases reversing direction of the geothermal gradient for short periods, and by causing changes in the mean atmospheric water abundance. The atmospheric water abundance will affect the gradient in vapor pressure between the buried ice deposits and the atmosphere and therefore will affect the balance between loss and resupply which controls the steady-state depth.

Conclusions: From the results of our numerical simulations we conclude that, as long as ice exists in the subsurface or can be resupplied from beneath, the steady-state depth will be maintained. The depth at which ice may be found is generally closer to the surface than previously thought (due to recondensation of vapor) and will not increase with time, but may oscillate slightly with climate changes around a mean depth. Ice found closer to the surface will have less regolith to diffuse through to reach the atmosphere. This will result in a larger loss rate and ice will completely disappear sooner unless a deeper subsurface source exists.

Equatorial ground ice may exist close enough to the surface to be detectable by long wavelength ground penetrating radar. If ice is found to currently exist at this steady-state depth, this could either confirm the existence of a deeper source capable of resupplying the ice deposits at least as fast as the loss rate, or the existence of a non-porous cap at the steady-state depth: a cap above this depth would allow ice to migrate along the geothermal gradient toward the underside of this non-porous cap.

The depth of a steady-state ice deposit also has implications toward rampart craters, terrain softening, and channel formation. Rampart craters may have formed from the entrainment of subsurface volatiles during impact. The interpretation of the latitudinal dependence of the minimum rampart crater size is that craters excavate into a ground ice layer, the depth of which varies with location and time. However, the steady-state depths for reasonable geothermal gradients may be much shallower than depths estimated from rampart craters and will not vary in time (until all the ice is gone, if there is no source). Similarly terrain softening may be affected by ground ice closer to the surface than previously suspected providing a thicker zone for creep deformation. Ice could be available closer to the surface for a longer period of time, which could suddenly melt to form outflow channels, rather than steadily becoming deeper and less available as water is lost to the atmosphere.
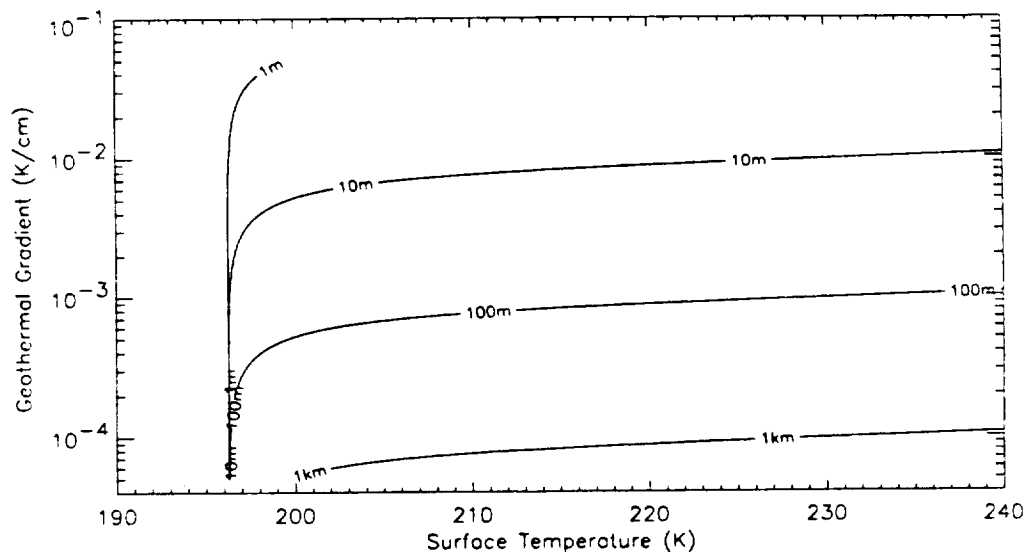

Fig. 1. Depth to the steady-state uppermost-occurrence of ice. These depths represent a balance between loss to the atmosphere and resupply from beneath following the geothermal gradient. Within the ice layer the geothermal gradient drives diffusion via the vapor pressure gradient. This simple model ignores the changes in thermal conductivity with depth as well as climate oscillations. The contours cut off at 196 K because we have chosen this temperature to represent frost stability with respect to the atmosphere.
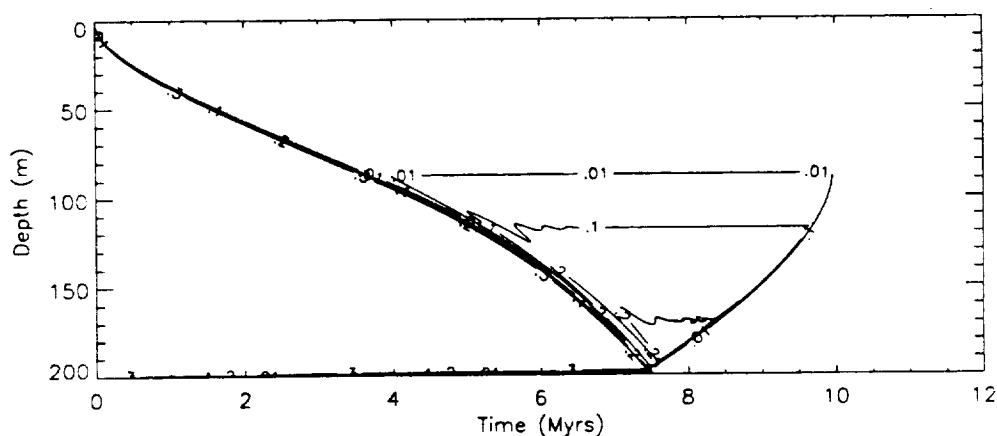

Fig. 2. Ice concentrations (g/cm^3) from a numeric simulation. Here we assume a mean surface temperature of 220 K and a geothermal gradient of 10^{-3} K/cm. 40% porosity is assumed, allowing a maximum of 0.37 g/cm^3 of ice as an initial condition.